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FUTURE AUTOMOTIVE MATERIALS - EVOLUTION OR REVOLUTION

P.Beardmore
Research Staff, Ford Motor Company

Abstract

An exciting era is evolving in the application of new materials technologies to automotive applications. The desire on the part of the automobile industry to completely satisfy the customers while concurrently meeting increasing demands and regulations for stringent emission control and fuel efficiency is opening a plethora of opportunities for new materials. In many cases, materials solutions are the only mechanisms for resolving some of the upcoming issues. The materials scientist and engineer will therefore have a primary role to play and will assume a position of significance hithertofore unseen in the automobile industry. The nature of the industry dictates that changes are primarily evolutionary with respect to chronology but nevertheless some of the future material changes will be revolutionary in nature. This presentation will treat three primary systems of the vehicle separately, based on the different materials approaches which will be adopted. These areas are (1)skin panels, (2)body structures and (3)powertrains. The competition between a variety of new materials in these 3 systems will be discussed in detail with the various tradeoffs being outlined. Amongst the more prominent of the new breed of materials will be new steel technologies, structural plastics (FRP), aluminum alloys (conventional and rapidly solidified), titanium alloys, metal matrix composites and smart materials (electrorheological fluids, etc.). The pace of development and application is accelerating rapidly and the impetus is likely to increase. Exciting materials days lie ahead!

NINETIES INFLUENCES

- Total Customer Satisfaction
- Competition
- Environment
- CAFE

APPLICATION STRATEGIES

- Skin Panels
- Body Structures
- Engine Components

APPLICATION STRATEGIES

- Skin Panels

- Body Structures

- Engine Components

FUTURE AUTOBODY MATERIALS MAJOR ISSUES

- Cost Effectiveness

- Lightweight

- Environment/Recyclability

POTENTIAL AUTOBODY MATERIALS

- High Strength Steels
- Engineering Plastics
- Structural Composites (FRP)
- Aluminum Alloys

SKIN PANELS
MAJOR ISSUES

- Cost Effectiveness
- Formability
- Functionality (Stiffness, CTE, Dent Resistance, Oil Canning)
- Lightweight
- Handleability/Damage Resistance
- Class A Surface Finish
- Paintability (Paint Adhesion, Etc.)
- Heat Resistance
- Repairability
- Recyclability

SKIN PANELS

- Mild Steel
- Bake Hardenable Steels
- SMC
- Thermoplastics
- Aluminum Alloys

FUNCTIONALITY

- Stiffness
 - Overall Panel/Closure Panel Stiffness
 - Local Panel Stiffness (Oil Canning)
- CTE
 - Fit and Finish
 - Interference
- Dent Resistance
 - Yield Strength Controlled

STEEL SKIN TECHNOLOGY

- Materials
 - Mild Steel
 - Bake-Hardenable Steels
- Advantages
 - Cost
 - Quality Control (e.g. Continuous Anneal Lines)
 - Formability
 - Experience (Vast Data Base)
 - Improved Dent Resistance (B-H)
- Limitations
 - Weight (?)
 - Deep Drawability (B-H)

PLASTIC SKIN PANELS

- Materials
 - SMC - Horizontal Panels
 - T/P - Vertical Panels
- Advantages
 - Design and Styling Versatility
 - Existing Experience Base
 - Few Structural Issues
- Limitations
 - Higher Cost
 - Temperature Limitations

SURFACE FINISH

- Long Period Waviness
- Short Period Waviness
- Local Defects (Pores, Etc.)
- Read Through (Welds, Ribs, Fibers)
- Quantitative Measurements

HEAT RESISTANCE

- E-Coat Temperatures (400F)
- Paint Oven Temperatures (280 - 325F)

SKIN MATERIALS

	Mild Steel	B/H Steel	SMC	T/P	Al
Cost	+	+	–	–	–
CTE	+	+	+	–	+
Surface	+	+	–	+	+
Stiffness	+	+	+	–	+
Formability	+	+	+	+	–
Joinability	+	+	–	–	–
Recyclability	+	+	–	+	+
Repairability	+	+	–	+	+
Lightweight	–	–	+	+	+
Dent Resistance	–	+	+	+	–
Heat Resistance	+	+	–	–	+

APPLICATION STRATEGIES

- Skin Panels

- Body Structures

- Engine Components

BODY STRUCTURES

MAJOR ISSUES

- Cost Effectiveness
- Lightweight
- Formability
- Functionality (Durability, Crash, NVH)
- Weldability/Joinability
- Repairability
- Recyclability

PRIMARY STRUCTURE

- Structural Integrity
- Sustain Primary Loads
- Manage Crash Loads
- Provide Acceptable Vehicle Dynamics (NVH)

BODY STRUCTURE MATERIALS

- Mild Steel
- High Strength Steels
- Aluminum Alloys
- Structural Composites (FRP)

BODY STRUCTURES
POTENTIAL WEIGHT REDUCTIONS

- High Strength Steels (Up to 15%)
- Aluminum Alloys (Up to 40%)
- FRP Composites (30-50%)

BODY STRUCTURE

- High Strength Steels
 - Yield Strengths 35-75 ksi
- Advantages
 - Cost
 - Property Control (e.g. Continuous Anneal Lines)
- Limitations
 - Formability
 - Weight (?)
- Aluminum Alloys
- Advantages
 - Lightweight
- Limitations
 - Cost
 - Formability
 - Joinability (?)

BODY STRUCTURE

Aluminum Alloys -- Two (2) Types of Construction

- Stamped and Bonded Construction
- Extrusions for Space Frame Construction

STRUCTURAL COMPOSITE PROCESSES

- HSRTM
 - Maximum Part Integration
 - Optimum Weight/Performance
 - Process Requires Development
- Compression Molding
 - Experience
 - Existing Materials

BODY STRUCTURE

- Structural Composites (FRP)

- Advantages
 - Lightweight
 - Low Investment Cost
 - High Part Integration

- Limitations
 - High Volume Capability
 - Fully Accounted Cost (?)

- Derivative Vehicle Structures

- Complete Composite Body Shells

BODY STRUCTURE

- Derivative Vehicle Structures
- Complete Composite Body Shells

- Derivative Vehicle Structures
- Complete Composite Body Shells

BODY STRUCTURE
ULTIMATE OBJECTIVE

- Primary Structure With Class A Surface Quality

BODY STRUCTURE MATERIALS

	Mild Steel	HSS	Al	FRP
Cost Effectiveness	+	+	-	?
Lightweight	-	+	+	+
Formability	+	-	-	+
Joinability	+	-	-	+
Repairability	+	+	-	+
Recyclability	+	+	+	-

APPLICATION STRATEGIES

- Skin Panels
- Body Structures
- Engine Components

ENGINE MATERIALS
TECHNICAL TRENDS

- Materials Only One Aspect
- Alternate Materials Consideration At Design Inception
- Wide Variety of Newer Materials

LIGHTWEIGHT ENGINE MATERIALS
POTENTIAL SYNERGIZED BENEFITS

- 5% Fuel Economy
- 50% NVH Improvement
- 35% Weight Reduction
- 25% Reduction in HC Emissions
- 10% Performance Improvement
- Improved Package Efficiency

GASOLINE ENGINE LIGHTWEIGHT COMPONENTS

Materials and Applications

- Titanium Alloys
 (Valves, Retainers, Connecting Rods, Springs)
- Rapidly Solidified Aluminum Alloys
 (Intake Valves, Connecting Rods, Retainers)
- Metal Matrix Composites
 (Pistons, Connecting Rods, Retainers)
- Fiber Reinforced Plastics
 (Piston Skirts, Connecting Rods, Retainers)
- Ceramics, Aluminides
 (Valves)

ENGINE MATERIALS

Valve System

Lightweight valve system components allow lower spring loads which reduce friction ----------> Fuel Economy Gains

Component	Material
Exhaust Valve	Titanium Alloy, Ceramics
Intake Valve	Ti, RS Al Alloy, Ceramics
Valve Spring Retainer	Titanium
Valve Springs	Titanium
Tappets	Al, MMC
Rocker Arms	Al, MMC, FRP

Power Conversion System

NVH and emissions improvements through weight reduction and lower crevice volume

Component	Material
Piston	MMC, Plastic Skirt
Piston Pin	MMC, Ceramic
Connecting Rod	MMC, RS Al Alloy, Titanium

ENGINE MATERIALS

Engine Structure

Weight, size, cost reductions and NVH improvement through use of innovative materials such as aluminum, magnesium and composites (metal or plastic matrix) for engine blocks, cylinder heads and manifolds.

ENGINE BLOCK MATERIALS

- Cast Iron -- Thin Wall
- Aluminum
- Magnesium
- FRP

FUTURE AUTOMOTIVE MATERIALS

Evolution and Revolution!

For the Material Scientist -- A Dream Come True!

AUSTEMPERING

Professor James P. Nagy

ERIE COMMUNITY COLLEGE
Main & Youngs Road
Buffalo, NY

PREREQUISITE The student should have knowledge of the topic, Isothermal Transformation Diagrams.

OBJECTIVE The object of this experiment is to observe the effects of nonequilibrium cooling of a carbon alloy steel. Various percentages of bainite and martensite will be produced in samples using the austempering heat treatment.

EQUIPMENT

Two heat treat furnaces
Rockwell hardness tester
Water quench tank
250 ML stainless steel beaker
Tongs capable of handling small samples
Tongs capable of handling a beaker half filled with molten lead
Hack saw
Pliers
Metallurgical polishing equipment
Metallograph or metallurgical microscope

SUPPLIES

3/8 inch (9.525 mm) diameter SAE 4140 steel bar stock
Lead chips (approximately 1 kg)
Cold mounting compound
2% nital etch
Bailing wire

SAFETY EQUIPMENT

Safety glasses
Heavy weight apron
heat resistant gloves

SAFETY PRECAUTIONS Students must wear their safety glasses, apron, and gloves when performing the heat treating part of this experiment. Students must wear safety glasses when etching the samples with the nital etch.

PROCEDURE

1. Set one heat treat furnace to 845 degrees Celsius

2. Set the other heat treat furnace to 400 degrees Celsius

3. Add a sufficient amount of lead to half fill the stainless steel beaker and place it in a furnace set at 400 degrees Celsius.

4. Each student will cut a sample from the SAE 4140 steel bar approximately 3 mm in thickness. Cut a grove on the edge of the sample about 1 mm in depth, and diagonally across the sample cut a second grove 1 mm in depth. Take a piece of bailing wire approximately 50 mm long and wrap it around the sample in the two groves making a wire handle on the sample.

5. The students in the laboratory class will break up into four groups.

GROUP A - will austenitize their samples at 845 degrees Celsius for 15 minutes, then quench their samples in the lead at 400 degrees Celsius for 10 seconds, then water quench their samples.

GROUP B - will austenitize their samples at 845 degrees Celsius for 15 minutes, then quench their samples in the lead at 400 degrees Celsius for 30 seconds, then water quench their samples.

GROUP C - will austenitize their samples at 845 degrees Celsius for 15 minutes, then quench their samples in the lead at 400 degrees Celsius for 60 seconds, then water quench their samples.

GROUP D - will austenitize their samples at 845 degrees Celsius for 15 minutes, then quench their samples in the lead at 400 degrees Celsius for 400 seconds, then water quench their samples.

NOTE - When the sample is removed from the 845 degree furnace and quenched in the lead at 400 degrees, the sample must be handled by the bailing wire handle. If the sample is held by tongs, the tongs will shield the sample from the lead and give an inadequate quench.

6. Remove any oxide coating or decarb and hardness test the samples using the Rockwell C scale.

7. Mount the samples in cold mount, polish, and etch the samples.

REQUIRED

1. Observe the samples under the microscope and determine the percentage of bainite and martensite.

2. Make a table of hardness of samples and time in the lead quench.

3. Make a table of hardness and percent bainite in the samples.

4. Make graphs of hardness and percent bainite VS time in the lead quench.

5. Using the Isothermal Transformation Diagram show the cooling cycle for each sample.

LABORATORY INSTRUCTORS NOTES

The key to this experiment is tc use a small sample of steel in order to get the sample to ccol at the desired cooling rates. Wrapping a bailing wire around the sample to use as a handle to hold the sample is of great importance.

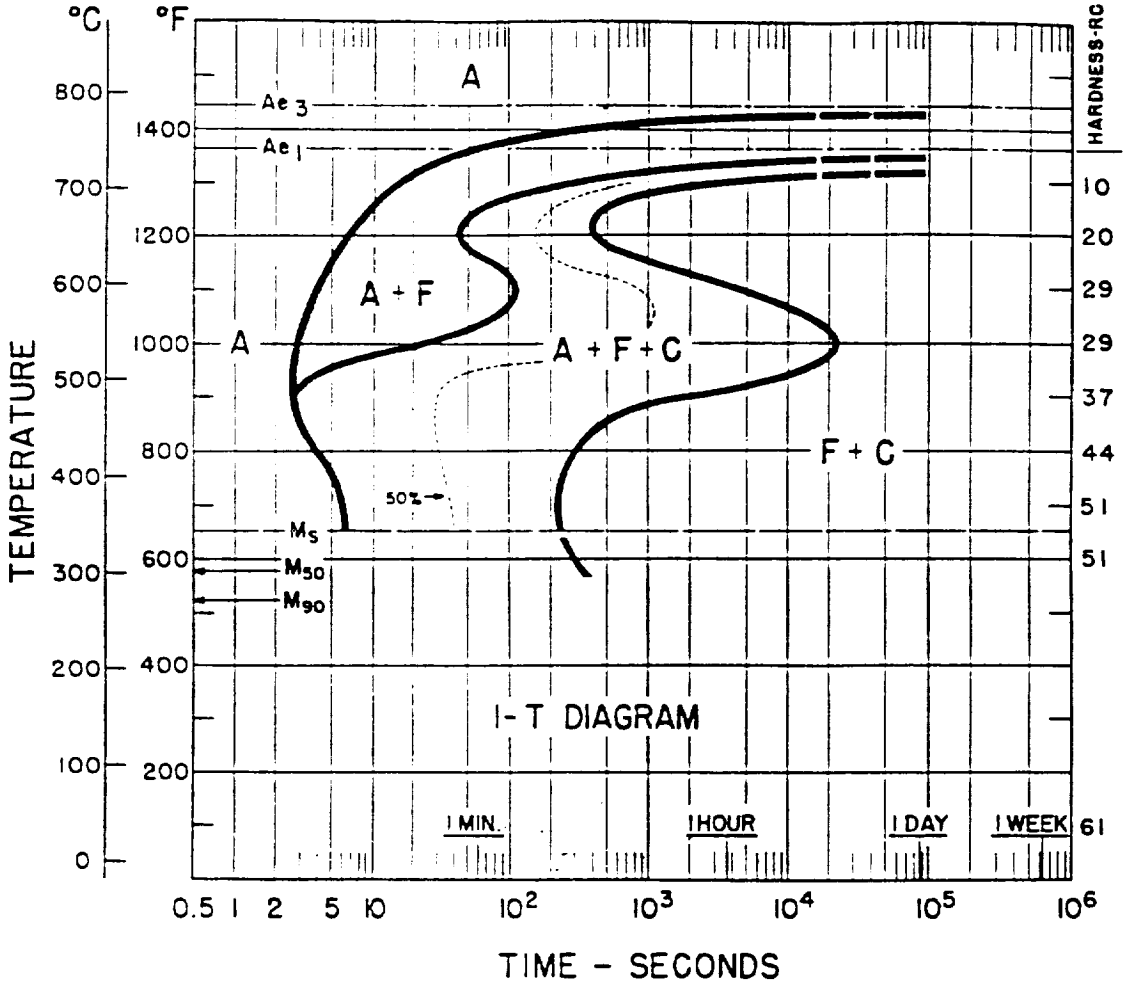
Have the students hardness test the samples before mounting them.

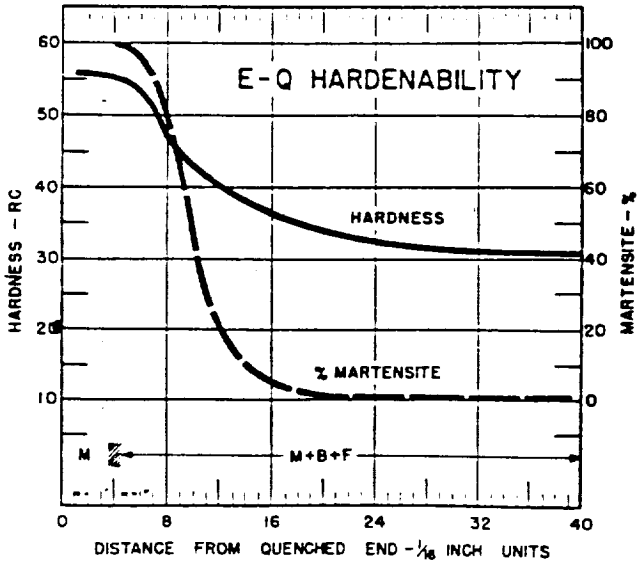
Steel will float in molten lead. Have the students make sure that the sample is not allowed to float.

The samples from group A will be all martensite. The samples from group B will contain just a slight amount of bainite. The bainite will etch much faster than the martensite and stand out, showing how the feathers of bainite are formed. The samples from group C will contain 30 to 50 percent bainite, and the samples from group D will be 100 percent bainite.

The bainite will show up best if the samples are lightly etched.

4140





4140

C-0.37 Mn-0.77
Cr-0.98 Mo-0.21

Austenitized at 1550°F

Grain Size: 7-8

LEGEND

A = Austenite	M = Martensite
F = Ferrite	B = Bainite
C = Carbide	P = Pearlite

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Brick, Pense, and Gordon. Structure and Properties of Engineering Materials. Fourth edition, New York: McGraw Hill, 1977. p 136-152.

Pollack, Herman. Materials Science and Metallurgy. Fourth edition, Englewood Cliffs, NJ: Prentice Hall, 1988. p194-208.

Jacobs and Kilduff. Engineering Materials Technology. First edition, Englewood Cliffs, NJ: Prentice Hall, 1985. p193-199

Title:
Hands-On Thermal Conductivity

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Key Words:
Thermal Conductivity, Insulation, Heat, Energy, Convection

Prerequisite Knowledge:
Essentially none, this experiment can be used at any level higher than about fifth grade.

Objectives:
To convey to the students the correct interpretation of something they have probably all noticed in everyday life, and to demonstrate the difference in thermal conductivity shown by a variety of materials.

Equipment and Supplies:
Samples of materials exhibiting the widest possible range of thermal conductivities, all in blocks of approximately equal size, about 10 x 2 x 2 cm. A good basic assortment would be aluminum, glass, firebrick and Styrofoam, as representing high, medium, low and very low conductivities, respectively. A look at a table such as the one attached will reveal other choices which may be more available locally and which will represent other points along the thermal conductivity scale.

Procedure:
Arrange the test materials, with reference numbers, on a tabletop. The following morning, invite several (or all) students to briefly place the back of their hands in brief contact with the test blocks. They will notice that some of the blocks appear to be colder than others, and should note the comparative coldness of the blocks on simple data sheets. Remind the students that the materials have been on the tabletop overnight and could not possibly be at different temperatures. So why do some feel colder than others? The students should be allowed to speculate, and should record their speculations in their notebooks. The correct answer is that our hands are richly supplied with nerves which sense the passage of heat energy into or out of our bodies. Since the skin is normally at a temperature of about 28 C (80 F) and the blocks are perhaps 5 degrees C colder, the "warm" or "cold" feelings result from faster or slower energy transfer, respectively, from us to the test blocks. So metals such as aluminum feel cold, while good insulators like Styrofoam feel warmer. The students have probably all noticed that different substances in a room feel as if they are at different temperatures, but few have actually thought about it enough to know why this is true.

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Sample Data Sheet:
This is obvious and will be omitted.

Instructor Notes:
Metals conduct heat better for the same reason that they conduct electricity better: their outer electrons are not localized but are shared by all of the atoms in the piece of metal. Their regular crystal lattice also helps the thermal energy, carried by vibrations called phonons, to travel better through metals. The glass does not possess this regular structure and is bonded such that outer electrons are localized and not shared. Much the same logic holds for the ceramic brick, except here conductivity is even lower because porosity has been intentionally left inside the brick. These pores are small and so do not support convection currents in the air filling the pores. This is the reason that fiberglass mat is good insulation; the fibers can fill space at a low density, meaning that not much material is present, and the fibers prevent formation of convective cells. Foamed plastics also make use of these tiny air bubbles to restrict the flow of heat. A piece of aluminum foil, crumpled very tightly, is a pretty good insulator, much better than solid aluminum, because of these small internal pores.

For energy efficiency, it is very important that houses be well-insulated. The material actually forming the insulation is not of much concern because its main function is to keep convection cells from forming and thus transferring heat from the inside wall to the outside wall. Since fibrous materials are very good at doing this, they should be non-flammable and non-toxic. Asbestos, a favorite natural insulation of the past, is being removed from many buildings at great cost because of its health hazard.

References:
Any college physics text will have a general explanation of thermal conductivity.
R. A. Flinn, P. K. Trojan, Engineering Materials and Their Applications, Third Edition, Houghton Mifflin Co., Boston, 1986, Pages 712-718.
J. A. Jacobs, T. F. Kilduff, Engineering Materials Technology, Prentiss-Hall, 1985.

Title:
Work-Hardening and Annealing in Metals

Author:
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Presenter:
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Battelle, Pacific Northwest Laboratories, Richland, WA

Key Words:
Work Hardening, Annealing, Dislocations, Strain Hardening, Recovery, Stress Relief

Prerequisite Knowledge:
Students should have some introduction to dislocations and slip in metals.

Objective:
To demonstrate to the students, in a hands-on manner, how a metal (copper) becomes more resistant to deformation as it is deformed, and how annealing may be used to restore the ductility of the metal. The experience provides a means of making dislocations more real to the student, and the ensuing discussion shows positive and negative effects of the phenomenon.

Equipment and Supplies:
Each student is provided with two pieces of #10 bare copper wire, about 20 cm long, and the students share a pair of common pliers which are used to make the original bends in the wire. For the annealing, a furnace capable of 225 C is required. If none is available, a home oven capable of 450 F will do.

Procedure:
After bending each piece of wire according to the sketch on the next page, The students are asked to grasp the wire sections by hand, then to twist the center section of wire through three complete revolutions. The students will note that this is fairly easy at first, but gets quite difficult. Why is this? After some discussion, the students should be told that the copper was originally in a soft or annealed condition and is being work hardened by the twisting. Each student should twist both segments of wire because they are to be compared after one is annealed.

Place one wire from each student into a furnace or oven, and heat to 225 C (450 F) for at least 2 h; turn the oven off and allow the wire to cool inside. The next day, take the wire samples out and redistribute. Note the darkened color of the wires; this is caused by surface oxidation during annealing. Each student will now twist the non-annealed wire through one more complete turn, then do the same for the annealed wire. The difference in the effort required will be quite obvious. How did the heat affect the cold-worked metal?

Instructor Notes:
Beyond the use of normal care, there are no unusual precautions for this experiment. Before the experiment, the students need to be told about the role of slip in the deformation of metals, and to be briefly introduced to

dislocations as a way in which slip is made easier. Essentially, dislocations make it unnecessary to lift an entire plane of atoms and move it in reference to the plane below it. It may be helpful to use the analogy of the carpet; if a carpet is slightly misplaced in a room, it is not necessary to lift the whole thing at once to move it. A much easier way is to make a small bump in the carpet, starting a wall or corner, then simply push the bump across the room. The entire carpet can be moved easily this way. It might be effective to demonstrate this, using a small piece (1-2 square meters) of carpet remnant or sample.

The reason why the copper becomes work-hardened is that the dislocations, which are originally fairly few in number, increase in number as deformation continues and get tangled with each other and with grain boundaries in the metal so that moving them becomes increasingly difficult. Annealing provides energy which can be used to move the dislocations out of the metal so that it can once again be deformed easily.

Positive Aspect: For metals that are to be used only at low temperatures where annealing cannot occur, cold-working can be used to increase the resistance to deformation. Metals differ in their sensitivity to work-hardening; copper was chosen because it work-hardens well and because it can be annealed at a relatively low temperature.

Negative Aspect: A work-hardened metal is more subject to breaking during forming then an annealed one. For example, metals are made into wire by pulling them through a series of holes in a die, each hole smaller than its predecessor. After most metals have been pulled through these holes, they work-harden to the point where they must be annealed before further forming is done or they are likely to break.

References:

R. A. Flinn, P. K. Trojan, Engineering Materials and Their Applications, Houghton Mifflin, 1986
R. E. Reed-Hill, Physical Metallurgy Principles, Van Nostrand, 1964

Sources of Supplies:

Bare copper wire is commonly used as a ground wire in electrical circuits, and can be obtained at any electrical supply house for about $0.40/meter. #12 Wire is even cheaper and could be used if #10 is not available, but it will twist much easier and the difference in effort when work-hardened may be harder to detect.

CERAMIC FIBERS

Bruce M. Link

Purpose

The purpose of this experiment is to demonstrate that glass ceramics are fundamentally stronger than everyday observation leads us to believe.

Acknowledgments and Intentions

This paper does not put forth any new ideas or particularly unique or original work, but rather is an assimilation of various text materials. It draws heavily upon basic work conducted by Griffith, Jurkov, Anderegg and others who experimented with ceramics in the early 1900's. The objective of this paper is to present an experiment that will readily demonstrate some of the basic properties of glass and ceramics.

Materials

2 Small "C" clamps balanced and drilled as in figure 1.
1 Spool of fine high purity aluminum wire (22 gage 17 stranded should work well. The finer the better)
1 Plastic bucket or other suitable lightweight container.
1 Precision scale good to 5g over a 10Kg range.
10 Kg of sand or other heavy substance. (lead shot will do)
10 Glass rods
1 Bunsen burner, gas supply and striker.
1 Micrometer good to .0005"
1 Safety glasses

Experimental Setup

Basically the two "C" clamps will be used to apply tension to either glass or metal fibers. One "C" clamp will have to be suspended from the ceiling or other suitable support structure. The second "C" clamp will be affixed to the bottom of the fiber and the bucket (or pannier) suspended from it. Weight will be added to the pannier until the fiber breaks. The diameter of the fiber will then be measured by means of the micrometer. Figure 2 shows the experimental setup.

Procedure

Aluminum Wire

1. Trim off a piece of aluminum wire approximately 50mm in length. Strip off the insulation and separate a single strand. Make several measurements along its length and determine its average diameter.

2. Place the strand in the setup as shown in figure 2 . Add weight until the fiber breaks. Measure the diameter of the shorter of the two pieces at the break. Determine the load on the fiber. Calculate and plot the breaking strength (weight/unit area).

3. Set the longer fiber up in the setup and repeat steps 2 and 3 until the longest fiber is too short to continue.

Glass Fiber:

1. Take one of the glass rods and heat it slowly and carefully over the Bunsen burner. Slowly draw out a glass fiber that is approximately 0.010" in diameter and 50mm long. Trim the fiber from the rod and place it in the fixture. Repeat steps 2 and 3 from the aluminum wire experiment.

Part II

1. Produce four fibers each of aluminum and glass as in Part I. Trim the fibers to the following lengths: 5mm, 10mm, 20mm and 40mm.

2. Measure the initial breaking strength of each fiber and plot the results.

Results

The results of part I of the experiment will show that the apparent breaking strength for both the glass fiber and the aluminum fiber increases as the procedure is repeated. The results for glass should be much more dramatic.

The results of part II of the experiment show something very different about the glass and the metal fibers. In both cases the strength of the fiber will tend to decrease as the length increases, but the curve for the aluminum fiber is much flatter than that for the glass fiber.

Discussion

It is possible to overlook the differences between the results for the glass and metal fibers and to say that the general trends are the same. If you do, you will not discover anything about glass. The questions that this experiment raises are

1. In part I why does the strength of the glass improve so radically? Why doesn't the metal strength improve as dramatically?

2. From part II why is it that the length of the fiber should have such a crippling effect on the strength of the fiber?

It is easy to explain the increase in the strength of the aluminum fiber from part I of the experiment as being due to work hardening of the entire fiber do to repeated loading. The measurements of the fiber diameter should be enough to convince you that this is taking place. However, the improvement in glass fiber strength cannot be explained by the same theory. If one looks at the measurements of the glass fiber diameter at the places where it broke, one should note that the fiber tends to maintain its average diameter. The metal fibers continually neck down.

Part II of the experiment provides a small clue to the breaking of glass fibers. If one's data is very good (this can be accomplished by repeating the experiment many times and averaging the results), one should be able to calculate the breaking strength of a glass fiber of zero length. It should be noted that this value will be much higher than that for the aluminum fiber. If a material is so theoretically strong, how is it that it can be so weak? An explanation for this can be helped along by taking one of the glass rods and slamming it against the table. Glasses are indeed brittle and non ductile. If one then imagines that there is a very small crack in the glass (a Griffith crack or one even larger), then this crack will

concentrate the stresses in the glass. Since the glass cannot ductilely deform to spread the stress very well, the stress will remain high and cause the crack to propagate. Metals, on the other hand, can dutilely deform and reduce the localized stress. This makes them more resistant to internal defects.

This line of reasoning also neatly explains the glass sensitivity to length. The shorter the fiber is, the lower is the probability of its having a serious defect (and almost any defect is serious for a ceramic in tension). The aluminum fiber will be less sensitive to length because it can plastically deform and negate the seriousness of most defects.

References:

1. Physical properties of glass, J.E. Sanworth, Oxford at the Claredon Press, 1950.

2. "Ind. Eng. Chem.," 1939,31,290, F.O. Anderegg.

3. "Phil. Trans. Roy. Soc.," Series A 1920,221,163, A.A. Griffith.

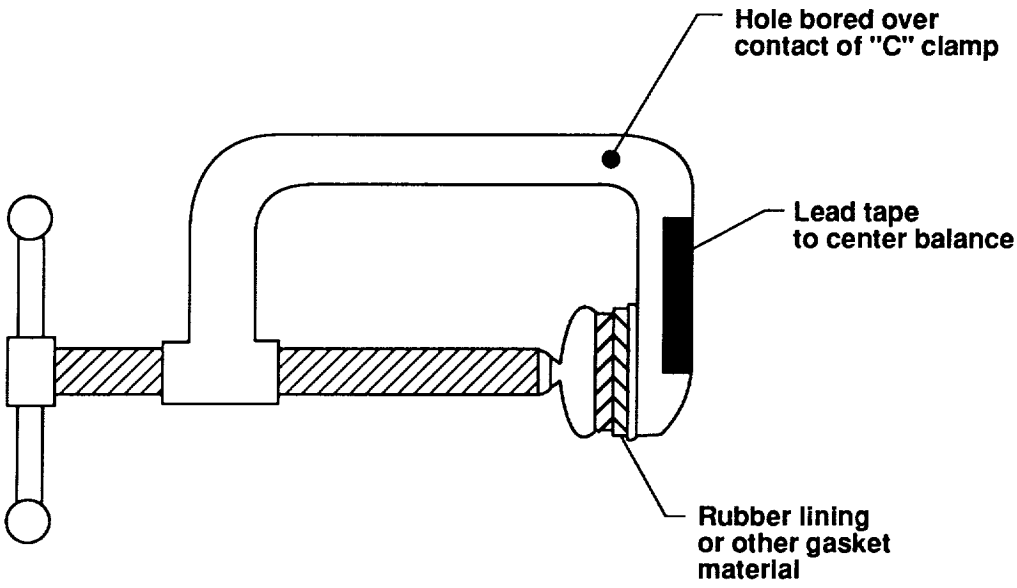


Figure 1 "C" Clamp Construction

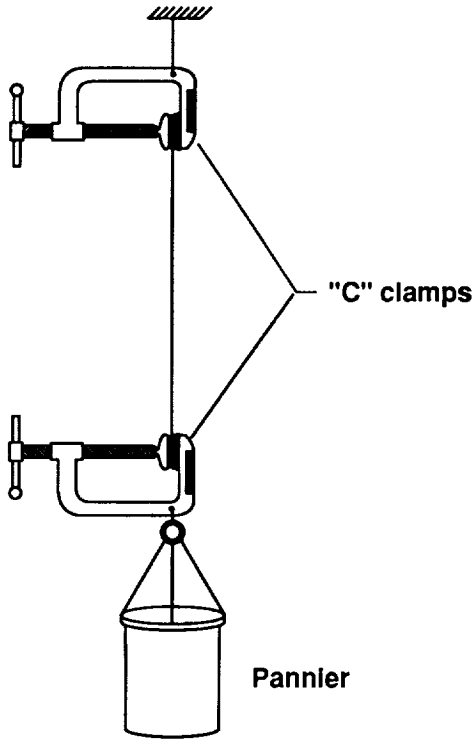


Figure 2 Experimental Setup

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National Aeronautics and Space Administration

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16. Abstract

This document contains a collection of experiments presented and demonstrated at the National Educators' Workshop: Update 89, held October 17-19, 1989 at the National Aeronautics and Space Administration, Hampton, Virginia. The experiments related to the nature and properties of engineering materials and provided information to assist in teaching about materials in the education community.

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